CHAPTER 6

SUMMARY

Soil and water, apart from people are among most important natural resources to sustain human society. Water is a natural annually renewable resource which is received on earth as precipitation either in the form of rain or snow. It is a part of the hydrological cycle. Man has been using this resource for various purposes through surface storage structures. Reservoirs play a major role in storing the required water supply for multiple purposes especially for irrigation water. These reservoirs have stabilized irrigation in India and substantially increased the food security and self-sufficiency.

India ranks among top five dam-building countries and by now have about 4500 large reservoirs (> 15 m height) and many small to medium reservoirs. These reservoirs are created by the construction of dam across Rivers that eventually stores water for longer duration but also decrease flow velocities and increase water spread area. The result is the deposition of suspended particles in the storage zone. The consequence of this is the loss of storage of the reservoir. According to World Commission on Dams, large dams in India are silted up at an average annual rate of 0.5%. It is also predicted that by 2020, 23% of India’s reservoirs which has 24% of national storage capacity may be affected by sedimentation. Another consequence of sedimentation is the accumulation of nutrients, pollutants and chemicals on the surface sediments which in turn affects the water quality of the reservoir. Eutrophication is a serious water quality problem in many reservoirs all over the world which triggers growth of algae or higher forms of plant life caused
by enrichment of water by nutrients, especially compounds of nitrogen and Phosphate. Runoff from soil erosion from the catchment area is one of the main causes for the Eutrophication process. Generally Phosphate is the limiting nutrient for phytoplankton in fresh water. When Phosphate is the limiting factor, a phosphate concentration of 0.01 mg/L is enough to support plankton and concentration from 0.03 to 0.1 mg/L or higher will be likely to promote algal blooms which prevent light penetration in the reservoir and depletes oxygen that result in fish kills. Therefore, eutrophication is a chronic environmental problem that will not abate easily and require serious management measures. Many important lakes in India like Hussein Sagar (Hyderabad), Nainital (Uttar Pradesh) and Dal (Jammu and Kashmir) have reportedly progressed to advanced eutrophication levels (Jain et al 2007, Reddy & Char 2004).

Hence the consequences of the sedimentation of the water bodies are therefore important for the continued beneficial uses of water by the society. Nature of watershed processes and land cover land use activities are important in the generation of sediment, its quality and transport. Therefore, managing the water quality of lakes and reservoirs primarily needs understanding of the sediment yield and its characteristics, besides the sedimentation and its impacts on the water bodies itself. Given the nature of water resources development, increasing demand for water, managing the reservoirs already constructed and to insure their continued beneficial uses, better understanding of these hydrological and water quality processes are essential.

A perusal of literature reveals that comprehensive information on sedimentation, loss of capacity or sediment Phosphate loads is limited from sub-tropical reservoirs. Moreover study of catchment processes, bathymetry of the reservoir and sedimentation surveys could provide necessary
information relevant for the long term planning and management of reservoirs. Better tools for such studies are available now like bathymetric and sedimentation surveys and provide reliable data on storage loss and water quality deterioration. A strategy to manage the problem of reservoir sedimentation effectively using latest assessment tools of quantity and quality are highly desirable to study the role of external and internal loads and hence will be the focus of the present study.

Krishnagiri Reservoir Project and its catchment area in Tamil Nadu, South India is chosen for the present study due to the fact that this project was the subject of a series of environmental investigations during the last decade. And the outcome of those investigations recommended a detailed investigation of various catchment processes responsible for the nutrient load and its impact on the reservoir water quantity and quality. This reservoir was therefore taken up for detailed investigation in this thesis and the results of the present study are summarized below.

Reservoir sedimentation was assessed using acoustic Doppler profiler and remote sensing data in ArcGIS environment, to derive bathymetry and estimate present capacity. As much as 52% of the reservoir capacity has been found reduced since 1957 at the rate of about 0.808 MCM for about 3 decades (1960-1990) and 0.826 MCM for the last five years. Measured depths were compared with IHH Poondi (IHH 2007) study, which reported a maximum depth of 12 m for this reservoir whereas the maximum depth measured in this study was 10.50 m. The differences noticed in depth values may be a result of 5 years of sedimentation in the reservoir compared to IHH study (2007).

The reservoir shows deeper zones of sedimentation along the original river course which may be due to the alignment of river sluices in dam along the river course. The water spread at FRL has been reduced to
10.96 km² because of the decrease in the inflow over the last five years which may be related to the failure of monsoon rainfall. Heavy sedimentation has taken place in 40 % of the water spread area which comprises mostly silt and clay in the middle part of the reservoir. The average organic matter content in the sediments was 15.15 % which went up to 46 %, especially in the deeper zone of the reservoir. This might indicate the nature of the external load retained from river inflows.

Total sediment Phosphate load in Krishnagiri reservoir varied from 6.84 kg to 23,394 kg depending on the zones of deposition. Among the four Phosphate fractions measured in the sediment, aluminium bound form is the major fraction (35%) of total phosphate. Al-P is a long term resident form in the sediment and indicates the potential load conditions. Fe-P is the second predominant form of Phosphate fraction found in the sediments (25%), which is highly mobile and can release phosphate in both oxic and anoxic conditions. Ca-P and SRP are minor components of (10% and 5%) Phosphate fractions in the sediment. Ca-P in the surface sediments is relatively stable under alkaline conditions but was found to be very low in Krishnagiri Reservoir. Al-P and Fe-P are susceptible to physical and chemical changes and their predominance suggests that temperature, pH and redox or other chemical reactions may be important means of P release from sediments.

The release rate of Phosphate from sediment to pore water varied from 10.22 mg/m² to 70 mg/m² which may be related to Fe-P and Al-P dominance. Internal Phosphate loading in Krishnagiri reservoir was calculated as 43.36 tons during the present study. Even when the external load is reduced or controlled, the process of eutrophication may not reduce immediately, because of the high internal phosphate load and its likely mobilization in Krishnagiri reservoir.
The RUSLE model was applied to Krishnagiri catchment in ArcGIS 9.3 environment at 90m pixel level to determine the annual soil loss from the study area. The result shows that the maximum annual soil loss is 219.805 t/ha/y which is considered as a severe erosion potential. High to severe eroding areas are restricted to the southern and north eastern part of the watershed. Around 93 % of the catchment area showed only low (0 – 5 t/ha/y) erosion rates. Among the sub watersheds middle and lower Ponnaiyar region has more high to severe eroding areas. The high erosion rates seen in these watersheds may be attributed to the higher erosivity; steeper slopes and the exposure of top soil surface without land cover.

The results indicate that the upper catchment area has low erosion potential as well as contribute more to the total soil loss, while in the lower part of the catchment, low erosion area remained higher, but contribution to the total soil loss of the subwatershed declined substantially (40-60%). Therefore moderate to severe eroding areas from the Markandanadhi and lower part of the catchment contribute significantly to the total soil loss.

Sediment Delivery Ratio (SDR) of the sub watersheds and the sediment yield from the sub watersheds reveal that Chinnar and Veppananpalli subwatersheds contribute only 2% each of the total soil loss whereas Lower Ponnaiyar (18.34%), Middle Ponnaiyar (15.34%) and Markandanadhi (29.79%) contribute more than 60% of the soil loss. Among the subwatersheds Lower Ponnaiyar basin deliver 23.66% of the sediment load (11963.67%) into the Krishnagiri Reservoir. More attention for soil conservation, therefore, must be focussed here. When combined with the Markandanadhi subwatershed, 48.08% soil loss (77906.23 t/yr) and 52.46% of sediment yield (26 526.02 t/yr) is together generated and needs attention for SWC measures.
The present soil erosion study has identified 34.76 km$^2$ as most erosion prone area. Among the eight subwatersheds Markandanadhi (11.36 km$^2$), Lower Ponnaiyar (10.06 km$^2$) and Middle Ponnaiyar (5.74 km$^2$) account for 78% of this area and needs immediate attention. The extent of coverage of erosion zones by SWC programs was assessed by excluding the highly eroding area identified by the present study that was covered by the present SWC programs of the government agencies. The soil loss estimation was simulated again with each of these P values (suggested from literature) and the corresponding areas of potential soil erosion zones and total soil loss in each case was estimated. Mulching (M), Minimum Tillage (MT) and Biofencing (BF) appear to be effective with reduction in different watersheds exceeding 90% of potential erosion areas. Total soil reduction from catchment was 80% in the case of Mulching and 62% in the case of Biofencing while all other results in less than 50%. The results of the simulation study suggest that Mulching and Biofencing can be effective in reducing total soil loss from the catchment area of the Krishnagiri Reservoir and may be considered for implementation.

The soil erosion study opened up new information regarding the potential erosion prone areas, changes in agricultural practices and its role on erosion in major part of the catchment area and the effectiveness of the SWC measures carried out at present. Further efforts at evaluation of SWC measures or sediment management in NPS control may be facilitated if a process based model could be developed for this watershed. It would then become a good management tool to plan and monitor soil erosion control as well as monitor NPS pollution source areas and evaluation of BMP’s to be implemented. This section presents the results of the SWAT model application in the study area.
Krishnagiri Reservoir catchment area was subdivided into 19 sub-basins and 333 HRUs using the process based model SWAT. The model predicted that mean annual rainfall for the total simulation period over the catchment area (864 mm) is mainly removed through evapotranspiration (ET) from the basin (69.7%), percolation/groundwater recharge accounted 16.7%, yielding a surface runoff of 13%. The computed water balance components indicated a good correlation with the observed runoff. Sensitivity analysis revealed Curve number of the watershed, Threshold water depth in the shallow aquifer (GWQMN) and Ground water revap co-efficient are the most sensitive parameters for stream flow and Average slope length of the basin, USLE support practice factor and Channel erodibility factor are the most sensitive parameter for sediment concentration.

In this study the goodness of fit was quantified by three model evaluation statistics such as Nash-Sutclifle Efficiency (NSE), Percent Bias (PBIAS) and coefficient of determination ($R^2$). Nash-Sutcliffe Efficiency (NSE) values for the monthly stream flow during calibration process was 0.89 and during validation period 0.83. The model performance in the present study for monthly stream flow based on NSE for both calibration and validation period can be rated as ‘very good’ and the PBIAS for stream flow shows a negative value for both calibration and validation period indicating the model has overestimation bias. The NSE value for sediment simulations are 0.73 and 0.76 during the calibration and validation period respectively. The PBIAS for sediment shows a positive value for both calibration and validation period indicating the model underestimation bias.

A critical evaluation of the hydrographs shows that the flow peaks are simulated slightly higher in the month of October 2001 whereas the highest flow peak in October 2005 with average discharge of 142.3 m$^3$/s was
simulated (145.2 m$^3$/s) accurately by the model. However low flows during the non-monsoon periods were not matched well. Similar to the calibration period, the simulated flows from 2006 to 2011 were slightly higher during low flows. The flow peak occurred in the month of October 2006 were over estimated by the model whereas high flow at the magnitude of 110 m$^3$/s in October 2010 are very well captured and simulated in the model. Simulated sediment concentration also followed generally the observed trend during both calibration and validation periods. Although, model predicted peak values were found higher than the observed values at different times in the watersheds, the difference was within reasonable limits.

After calibration and validation of the model it was found that among the eight sub watersheds, Lower Ponnaiyar shows highest sediment yield of 60523 t/yr where as Veppanapalli sub watershed yields only 906.53 t/yr. High sediment yield is seen in the outlets of Lower Ponnaiyar, Middle Ponnaiyar and Sulagiri sub watersheds. These sub watersheds have high agricultural activity with steep topography. This may be one significant reason for high sediment yield from these sub watersheds.

The effect of Soil and Water Conservation practices on sediment yield is obtained by varying the USLE_P factor in the SWAT model at Sub basis or HRUs. Results of the simulation on sediment yield under different conservation practices in the catchment area shows that Mulching generated lowest value of sediment yield (29642.64 t/yr), then Bio-fencing (56413.75 t/y) followed by Minimum Tillage (72836.15 t/y), Field bunding (91335.73 t/y) and stone walls (103241.11 t/y). Vegetative practices like mulching and bio-fencing are the best methods among the selected SWC measures since the reduction in sediment yield is 71 % in the case of minimum tillage operation and 62.1% in the case of bio-fencing.
This study suggests that soil conservation programs at the catchment level need to be intensified / improved to prevent soil erosion from the catchment. This could eventually reduce the eutrophication problem for the reservoir. However, a long term planning of catchment and reservoir management together is required to increase the life time of the reservoir and improve water quality.